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IEA/SH&C/T18

B13 FINAL REPORT

B13: Directional Optical Properties Measurements

FINAL PROJECT REPORT

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1 INTRODUCTION

Within the IEA/TASK 18 which deals with advanced glazing materials for solar and building applications, several projects are dedicated to the optical measurements. The B13 project is one of those : its specific purpose is directional optical properties, and the detailed aim is, using the words agreed by the participants during the 3rd EM in Sydney : [T18/B13/IR2/93]

« to improve the knowledge of the optical properties of all sorts of glazing materials as a function of the incoming radiation incidence angle, and to provide relevant data in this field for a better characterisation of glazing elements for comfort and energy saving.

For that, the participants will take advantage of all the various measurement equipment available between them, to collect and compare data, to improve and harmonize the measurement procedures, and to validate the results obtained on large samples by a good understanding of the same measurement on small samples, performed with more accurate equipment. »

This project definition places it between several other projects : it is concerned more with macroscopic effects of the incidence angle on the optical properties, and deals with large size samples (even complete glazing units).

It is situated downstream from the B11 project on scattering which is working on small samples. On the other hand, B13 as well as B11 provide results and data to the B12 and B14 projects, dedicated respectively to TSET and U values which are directly related to comfort and energy saving characterization.

From the beginning the measurement activity needed an agreement on the terminology, and a comprehensive survey of the specific available equipment.

The main deliverables of the measurement programme are obviously of two types :

- first : a large number of data covering a wide range of glazing product types,
- second : recommendations based on this experimental work that allows us to specify improved measurement procedures, to guarantee a better fit to the product family specifications.

These statements contain in fact the main items of this report which are :

1. terminology;
2. equipment survey.
3. measurement campaign : results and comments.
4. recommendations for measurement procedures.

2 TERMINOLOGY

The beginning of the common work was dedicated to harmonising our terminology, concerning the identification of the optical factors (wavelength, geometry ...)

The optical factors (transmittance, reflectance, absorptance and emittance) are perfectly identified when one knows three characteristics about them :

1 the spectral range.

2 the structure and surface properties of the material concerned.

3 the angular description of the incoming and out going radiation.

For our purpose with glazings, we generally separate the spectral range in two regions : the <u>solar range</u> covering the visible and the near infrared regions, and the <u>"infrared range"</u> which corresponds here to the emittance wavelengths of the black body between -50°C and +100°C.

The material macroscopic appearance and especially its heterogeneous or homogeneous character will determine two families of products : the first one concerns homogeneous materials both in surface and structure. These materials can be characterised by cutting <u>small samples</u> (about 100 x 100 mm) for measurements. The second family consists of materials the surface or bulk structure of which is so heterogeneous at the macroscopic scale that <u>large samples</u> (100 x 100 mm and larger) are necessary to perform relevant optical measurements.

Finally one must determine the angular geometry of the incoming and out going radiation to describe precisely the optical factors required. This last characterisation is described in table 1, providing diagrams and definitions of most of the possible geometry of measurement. This terminology has been agreed within B13 project and also within the task. For example A1 documents include the same table. It is intended for mainly from international standards or recommendations.

3 EQUIPMENT SURVEY

The laboratories involved in optical characterization are very familiar with the use of commercial spectrophotometers, but for directional measurements on complex glazing, these devices are not suitable, and each team has developed specific equipment for that purpose along the years.

It appeared necessary within the B13 group to describe each of those unique devices in detail, using a common format, as far as possible.

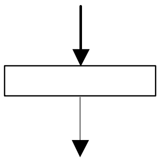
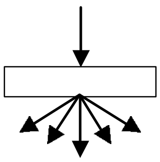
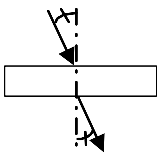
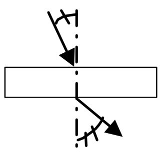
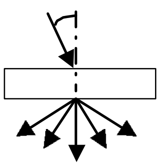
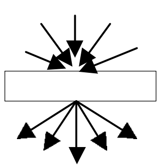
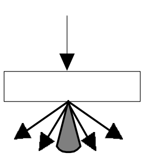
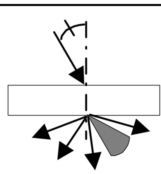
3-1. DESCRIPTION OF THE MEASUREMENT CAPABILITIES

The optical factors described previously have been listed in four tables (tables 2, 3, 4 and 5) for each spectral range and each material family. The names of the participating countries appear in the boxes for which they have available equipment. A difference is made between the equipment providing a spectrum in the range, and the equipment giving only a broadband value, for a part of the range.

These tables summarize the information given directly by the participating countries, and indicate all the equipment available now. The descriptions are a condensed summary of detailed information found in the report from NL (January 1994) called « inventory of measurement equipments » (Ref. T18/B14/WD1/94).

Table.1 Optical factor illustrations and Terminology

B 13	T 18 /b13 / PL/ 94 15 January 1994	OPTICAL FACTORS ILLUSTRTION AND TERMINOLOGY

	τ^{nn} normal normal transmittance	
	τ^{nh} normal hemispherical transmittance	
	τ^{dd} (τ^{db}) bidirectional regular transmittance	
	$\tau^{dd'}$ bidirectional transmittance	
	τ^{dh} directional hemispherical transmittance	
	τ^{hh} hemispherical hemispherical transmittance	
	$\tau^{n\ diff}$ ($\tau^{n\ *}$) normal diffuse transmittance	
	$\tau^{d\ diff}$ ($\tau^{d\ *}$) directional diffuse transmittance	

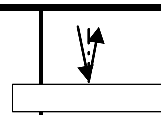
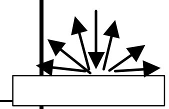
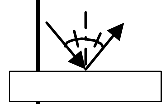
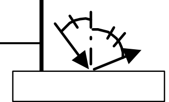
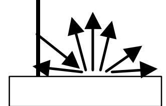
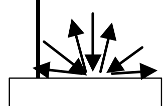
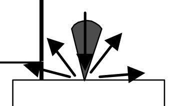
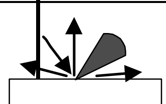
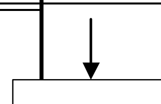
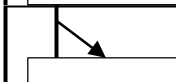
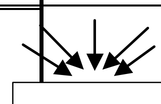
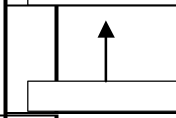
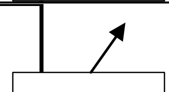
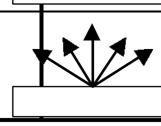
	ρ^{nn} normal normal reflectance	
	ρ^{nh} normal hemispherical reflectance	
	ρ^{dd} (ρ^{db}) bidirectional specular reflectance	
	$\rho^{dd'}$ bidirectional reflectance	
	ρ^{dh} directional hemispherical reflectance	
	ρ^{hh} hemispherical hemispherical reflectance	
	$\rho^{n\ diff}$ ($\rho^{n\ *}$) normal diffuse reflectance	
	$\rho^{d\ diff}$ ($\rho^{d\ *}$) directional diffuse reflectance	
	α^{n} normal absorptance	
	α^{d} directional absorptance	
	α^{h} hemispherical absorptance	
	ε^{n} normal emissivity	
	ε^{d} directional emissivity	
	ε^{h} hemispherical emissivity	

table 2

B13	I.E.A. / T18 /B13 /94 June 1994					
OPTICAL FACTOR MATRIX		**SOLAR SPECTRAL RANGE**				
		SPECTRAL (λ) [1]	BROAD BAND[2]			
			Ultra violet (uv)	Light (v)	Solar (e)	colour (L,a,b)
normal / normal	τ^{nn}	FRA FRG IT JAP NL SWE CH UK USA				
	ρ^{nn}	FRA FRG IT NL JAP SWE USA				
normal / hemispherical	τ^{nh}	FRA FRG IT JAP NL SWE CH UK USA		FRA IT	FRA USA	FRA
	ρ^{nh}	FRA FRG IT NL JAP SWE USA		FRA IT	FRA	FRA
bidirectional / specular/regular	τ^{dd}	FRA NL SWE UK USA		SWE USA		
	ρ^{dd}	FRA NL SWE USA		SWE USA		
bidirectional / (general case)	$\tau^{dd'}$	FRA USA		SWE USA		
	$\rho^{dd'}$	FRA USA		SWE USA		
directional / hemispherical	τ^{dh}	FRA NL SWE		SWE		
	ρ^{dh}	FRA NL SWE		SWE		
hemispherical / hemispherical	τ^{hh}					
	ρ^{hh}					
normal / diffuse	$\tau^{n\ diff}$	FRA FRG NL SWE CH USA		SWE		
	$\rho^{n\ diff}$	FRA FRG NL SWE CH USA		SWE		
directional / diffuse	$\tau^{d\ diff}$	NL				
	$\rho^{d\ diff}$	NL				
normal	α^{n}					
directional	α^{d}					
hemispherical	α^{h}	UK				
SMALL SAMPLE						

[1]and by calculation, total at measurement temperature
[2] broadband only, <u>not</u> by calculation from spectral

table 3

B13	I.E.A. / T18 /B13 /94					
	June 1994					
OPTICAL FACTOR MATRIX		SOLAR SPECTRAL RANGE				
		SPECTRAL (λ) [1]	BROAD BAND[2]			
			Ultra violet (uv)	Light (v)	Solar (e)	colour (L,a,b)
normal /	τ^{nn}	FRA		USA	FRA UK	
normal	ρ^{nn}	FRA		USA	FRA	
normal /	τ^{nh}	FRA NL IT		IT SWE UK	DK FRA CH UK USA	
hemispherical	ρ^{nh}	FRA NL		IT SWE UK	FRA	
bidirectional /	τ^{dd}	FRA		FRG NL USA	FRA	
specular/regular	ρ^{dd}	FRA		FRA FRG USA	FRA	
bidirectional /	$\tau^{dd'}$	FRA		FRG NL USA	FRA	
(general case)	$\rho^{dd'}$	FRA USA		SWE USA	FRA	
directional /	τ^{dh}	FRA FRG* NL,IT		FRG IT SWE UK	DK FRA FRG CH UK	
hemispherical	ρ^{dh}	FRA FRG* NL		FRG IT SWE UK	FRA FRG	
hemispherical /	τ^{hh}	FRG*		FRG SWE IT	DK FRG	
hemispherical	ρ^{hh}	FRG*		FRG SWE IT	FRG	
normal /	$\tau^{n\ diff}$	FRA FRG NL SWE CH USA IT		SWE		
diffuse	$\rho^{n\ diff}$	FRA FRG NL SWE CH USA		SWE		
directional /	$\tau^{d\ diff}$	NL				
diffuse	$\rho^{d\ diff}$	NL				
normal	α^{n}	IT				
directional	α^{d}	IT				
hemispherical	α^{h}	UK				
LARGE SAMPLE						

[1]and by calculation
[2] broadband only, <u>not</u> by calculation from spectral
* FRG only between 300 and 1600 nm

table 4

B13	I.E.A. / T18 /B13 /94		
	June 1994		

OPTICAL FACTOR MATRIX		INFRARED SPECTRAL RANGE			
		SPECTRAL (λ) [1]	BROAD BAND[2]		
			Total (amb temp)	Total (100°C)	Total (variable temp)
normal /	τ^{nn}	CH FRA FRG IT JAP NL SWE UK USA			
normal	ρ^{nn}	FRA IT JAP NL SWE USA			
normal /	τ^{nh}	CH SWE			
hemispherical	ρ^{nh}	CH NL SWE			
bidirectional /	τ^{dd}	FRA SWE			
specular/regular	ρ^{dd}	FRA NL SWE UK			
bidirectional /	$\tau^{dd'}$				
(general case)	$\rho^{dd'}$				
directional /	τ^{dh}				
hemispherical	ρ^{dh}	NL			
hemispherical /	τ^{hh}		NL	NL	
hemispherical	ρ^{hh}		NL	NL	
normal	ε^{n}	JAP*	FRA NL	FRA NL	
directional	ε^{d}		FRA UK NL		
hemispherical	ε^{h}		FRG** NL UK	NL UK USA	FRA
SMALL SAMPLE					

[1]and by calculation
[2] broadband only, <u>not</u> by calculation from spectral
* JAP between 3 and 25 µm,
** FRG at 60° C

table 5

B13	I.E.A. / T18 /B13 /94		
	June 1994		

OPTICAL FACTOR MATRIX		INFRARED SPECTRAL RANGE			
		SPECTRAL (λ) [1]	BROAD BAND[2]		
			Total (amb temp)	Total (100°C)	Total (variable temp)
normal / normal	τ^{nn}				
	ρ^{nn}				
normal / hemispherical	τ^{nh}				
	ρ^{nh}				
bidirectional / specular/regular	τ^{dd}				
	ρ^{dd}				
bidirectional / (general case)	$\tau^{dd'}$				
	$\rho^{dd'}$				
directional / hemispherical	τ^{dh}				
	ρ^{dh}				
hemispherical / hemispherical	τ^{hh}				
	ρ^{hh}				
normal	ε^{n}	FRG			
directional	ε^{d}	FRG			
hemispherical	ε^{h}				
LARGE SAMPLE					

[1]and by calculation
[2] broadband only, <u>not</u> by calculation from spectral

3-2. SPECIFIC CAPABILITIES FOR DIRECTIONAL OPTICAL MEASUREMENTS ON INHOMOGENEOUS MATERIALS

The main difficulty in measuring optical factors lies in making directional measurements on inhomogeneous samples. The purpose of B13 project is essentially to make progress in this direction so that some recommendations may be issued based on the work performed, in order to reach better agreement and less discrepancies between the laboratories.

The starting point of this work is that part of the two diagrams related to large samples where directional measurements are concerned. One can see that, except for FRG for directional emittance, the group has no expertise in the infrared range, and table 6 gives the relevant enlarged part of the table 3. It appears that 9 countries share in common measurements, which is quite a large group, where significant progress should be expected. In table 6, the numbers refer to the page of the NL document indicated previously where the equipment is described ; L is for left and R for right. (Ref. T18/B14/WD1/94). This table Was used to plan the measurement campaign on several material families.

Finally, each specific device capable of accepting large size samples is described in a more detailed format sheet. One sheet is actually available for 10 test rigs: (Ref. T18/B13/WD1/97)

DK1 : SOLTRANS (TIL)
FRA1 : Megasphère (CSTB)
FRA2 : COSMI (CSTB)
FRG1 : TAUWIN + RHOWIN (FhG /ISE)
IT1 : Labsphere + collimated beam (SSV)
IT2 : Labsphere + hemispherical irradiation (SSV)
IT3 : CATRAM (ENEA)
FIN: Laser Prexsion Rk 5100 pribe Rhp 545 (VTT)
NL1 : 65 cm integrating sphère (TNO)
UK1 : 1,2 m and 800 cm integrating sphère (UWCC)

OPTICAL FACTOR MATRIX		SOLAR SPECTRAL RANGE				
		SPECTRAL (λ)	BROAD BAND			
			Ultra violet (uv)	Light (v)	Solar (e)	Colour (L,a,b)
bidirectional /	τ^{dd}	FRA (20L)		FRG (22R) NL (32L) USA (56L)		
specular/regular	ρ^{dd}	FRA (20L)		FRG (22R) USA (56L)		
bidirectional /	$\tau^{dd'}$	FRA (20L)		FRG (22R) NL (32L) USA (56L)		
(general case)	$\rho^{dd'}$	FRA (20L)		FRG (22R) USA (56L)		
directional /	τ^{dh}	FRA (19L) NL (30R) FRG (-) IT		FRG(23L) IT (-) SWE(42R) UK(50R)	DK(13L) FRG(23L) CH(-) UK(50L)	
hemispherical	ρ^{dh}	FRG (-) IT*		FRG(23L) IT (-) SWE(42R) UK(50R)	FRG(-)	
hemispherical /	τ^{hh}	FRG (-)		FRG(24L) IT SWE(42R)	DK(13L) FRG(24L)	
hemispherical	ρ^{hh}	FRG (-)		FRG(24L) IT SWE(42R)	FRG(24L)	
LARGE SAMPLE						

Table 6 Measurement capabilities for directional optical factors - Reference are to the page of the NL Document « Inventory of Measurement Equipment » (January 1994)

* Calculated from the measurement τ^{dh} and α^{dh}.

4 MEASUREMENT PROGRAMME

Having established the terminology and the equipment available, a large measurement campaign has been undertaken with a logical progression from clear glass to very complex units. In fact, this campaign was not specific for this project, but B13 benefited from the measurement programmes undertaken by other projects, best taking more interest in what was related to directional global characterization.

The non diffusing double glazings have been tested in B11, B12, B13 and B14.

The diffusing sample has been circulated for B11 and B13.

The geometric media were issued from B2, the aerogel window came from B1.

The idea which guided the experimental work was the following :

- measure in the specific devices some simple materials which can be characterized in more conventional equipment (for calibration purpose).
- proceed to more complex samples (diffusing → unhomogeneous → with mechanical devices inside → complete window unit) but never before obtaining agreement in results amongst the laboratories in the previous step.

In fact, work proceeded in that way from the non diffusing DGU to the diffusing sample, then from the diffusing sample to the geometric media. The aerogel window was tested in parallel.

4-1. DOUBLE GLAZING UNITS

This part of the optical characterization was performed by seven laboratories each of whom tested in the directional/ hemispherical transmittance mode for two double glazed window units which each had a coated glass.
The samples were distributed in 1994 to all Task 18 laboratories by the manufacturers. They are all actual window units, the size of which has been ordered by the laboratory, ranging between 0.4 and 1.2 m2.
The Pilkington unit consists of a K-glass pane (highly transmitting low- E coating) and an ordinary float glass
The Interpane units consists of an Ipasol Natura 52/38glass pane (solar control coating) and an ordinary float glass

4-1.a. Results

All the results are reported in Table 7, and plotted in Fig.1 and Fig.2. They are expressed in terms of direct/hemispherical transmittance. These data are obtained directly with broadband detectors by FRG, NL, and UK. When pyranometers and natural sun are concerned (DK and CH), the solar data have been corrected to take diffuse radiation into account. The solar transmittance given by FRA is the result of the integration of the spectral curves according to PrEN 410. Finally, SWE produced integrated results from small sample data separately, by calculation according to ISO 9050, followed by integration of the spectra according to ASTM/ E 891.

COUNTRY		Angle of incidence (deg) 0	10	20	22.5	30	40	45	50	60	70	75	REMARKS P=pyranometer C= calculated
	DK	54.7				53.7		49.9		43.9			P
	FRA	54.3				52.2		47.3		41.9			
PILKINGTON	FRG	52.3		51.0		50.1		47.5		35.8	34.6		
KGlass	NL	55.9	55.2	54.8		53.6	52.4	51.9	31.2	44.9	34.0	24.0	
	SWE	53.4								40.6			C
	CH	54.2				50.3		45.9		39.9	32.4		P (corrected)
	UK	58.1		57.2		56.6		54.1		46.7	33.1		
	DK	36.2				35.3		38.8		28.6			P
	FRA	35.1				32.6		30.9		25.5			
INTERPANE	FRG	31.3		30.8		30.3		29.6		26.5	21.5		
Ipasol	NL	36.3	35	34.6		34	52.4	32.1	31.2	27.3	20.5	15.2	
Natura 66/34	SWE	31.5								24.5			C
	CH	34.1				32.1		28.9		23.6	20.3		P (corrected)
	UK	37.7			35.5			32.5		28.1			

Table 7: Integrated solar directional/hemispherical transmittance for Pilkington and Interpane DGU

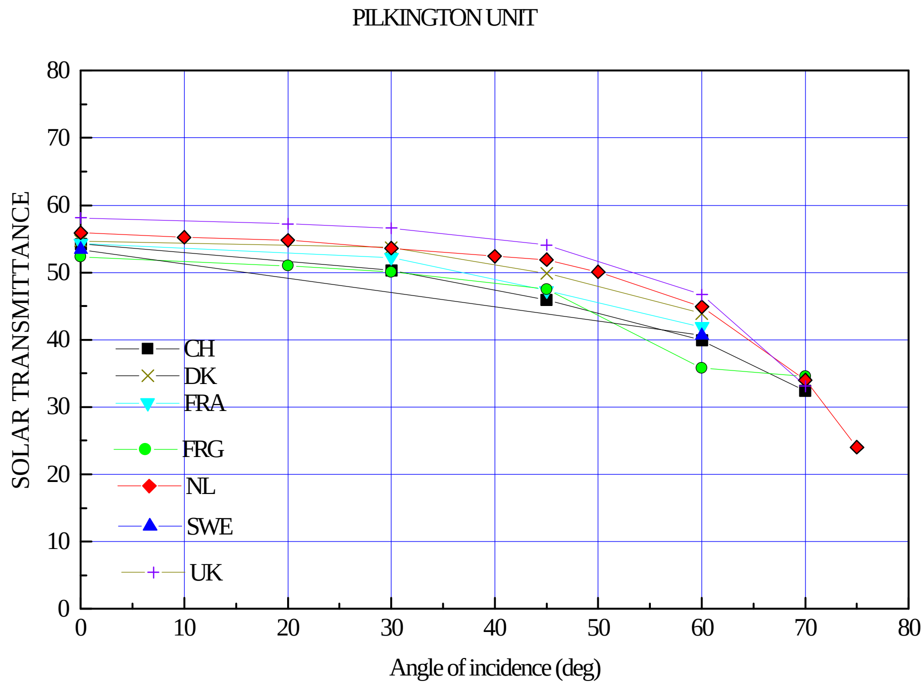


Figure 1: Normal/hemispherical solar transmittance versus angle of incidence: Pilkington Kglass DGU

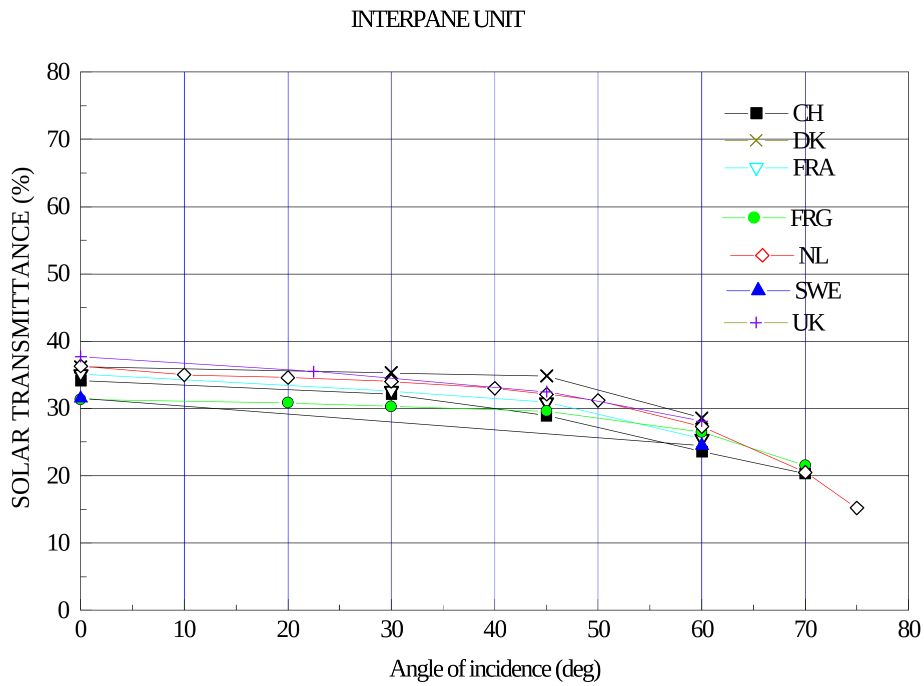


Fig 2: Normal/hemispherical solar transmittance versus angle of incidence: Interpane Natura 52/38DGU

4-1.b. conclusions.

The results presented here have been obtained by quite different experimental methods and devices. Consequently, there are relatively large differences, reaching several percent. In Table 1, the highest value is typically 5-6 percentage points higher than the lowest value. These differences may be due to different spectra of the light sources, different sensitivity of the detectors, errors originating from the geometry of the test set-up and discrepancies between tabulated solar spectra used for the integration and actual spectra of the light sources used for the broadband measurements.
For instance, if we consider the spectral range, we note that the silicon detectors used for the broadband measurements have a limited band width. This could explain some of the discrepancies in the results of the different methods, although the contribution to the solar spectrum after 1.1 micron is quite small and the transmittance of the sample is low. The calculation out of the spectral results from the Megasphere have been extrapolated as the spectrum only covers the 380-1700 nm range, while the solar spectrum used for the integration is spread from 350 to 2500 nm. About 10 percent of the solar energy is contained outside the measured spectral range. For the small samples the measured spectral range completely covers the solar one.
Considering the differences in measurement techniques and the various problems involved, the agreement between the results is quite satisfactory. Nevertheless, it is interesting to note that there are also differences between the results obtained by the same technique, and that these differences are as large as, or even larger than those between different techniques.

It is of major importance for the future characterisation work, especially on more sophisticated products than the classic D.G.U., that results obtained by different methods be in agreement, and that when they disagree, it is possible to track down the reasons for the discrepancies, and to make appropriate corrections. It is not acceptable that the values for key glazing parameters obtained in different laboratories and/or with different techniques differ by as much as 10 percent.

For this reason, it is important to continue with this type of comparison between different methods in order to evaluate the accuracy and to provide recommendations for the different measurement procedures.

4-2. DIFFUSING SAMPLES

This part presents the optical characterisation of PTFE-01, a Teflon film sample. The purpose of this is to test the potential of using this as a thin reference material to improve the calibration agreement of the measurement devices used in Task 18 for large and small samples characterisation, in conjunction with the B11 project.
The sample (PTFE-01 ISOFLON) was distributed by the CSTB to all laboratories. Seven laboratories have performed measurements, five of whom have performed measurements at different angles.. This report presents the results and shows the difficulties encountered in the measurement of the diffuse, specular and total components of a highly scattering sample

4-2.a. Results

The following tables show the experimental results from the different laboratories.
For the normal diffuse(table 8) and the normal hemispherical components (table 9), the results show a relatively good agreement.
The comparison of the spectral curves (fig 3) confirms the good agreement.

Normal/hemispherical measurements				
Laboratories	τ^{nh} visible	τ^{nh} solar	ρ^{nh} visible	ρ^{nh} solar
FhG/ISE broadband measurement	74.2	83.9	--	--
FhG/ISE spectral measurement	73.5	80	27.5	21
CSTB spectral measurement	73.3	79.4	28.8	23.5
TNO	75.9	84.3	28.3	21.3

ENEA spectral measurement	74.5	81.8		
SSV broadband measurement	74.7	--	25	--
TIL broadband measurement	--	83	--	--
UWCC	--	76.1	--	17.6

table 8: Normal/hemispherical measurements on diffusing sample

Normal/diffuse measurements				
Laboratories	τ^{ndiff} visible	τ^{ndiff} solar	ρ^{ndiff} visible	ρ^{ndiff} solar
FhG/ISE spectral measurement	72	67	27.5	21.1
TNO	69.8	67.6		
CSTB spectral measurement	71.1	64.05	28.5	23.1
UWCC		66.8		

table 9: Normal/diffuse measurements on diffusing sample

It is important to notice that the spectral measurements from FhG/ISE and from CSTB were made with the same instrument(Perkin Elmer Lambda 19). It is the explanation of the good agreement between these two labs on the normal diffuse and the normal hemispherical components

If we compare the results of different procedures or instruments(description in doc T18/WD1/97), we note that the results disagree: For the FhG/ISE, the solar factor measured with the broadband measurement is greater by 4% than the solar factor measured with the spectral measurement (80%, 83.9%). The transmitted light reflected inside the sphere will partly depend on the sphere wall reflectance of the instruments. and the diffuse components are drastically dependent on the characteristics of the integrating sphere and of the incident beam.

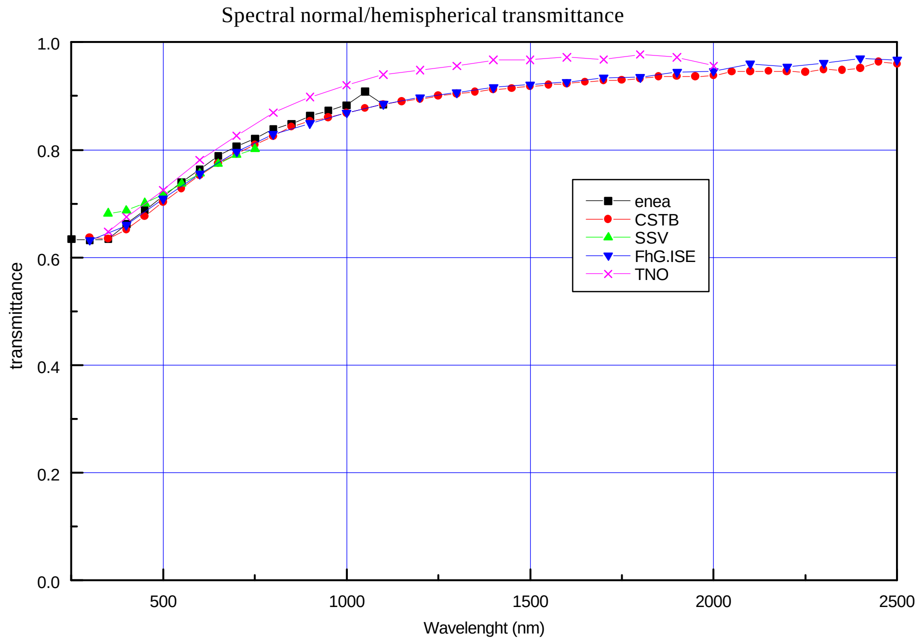


figure 3: comparison of the spectral normal/hemispherical transmittance on diffusing sample

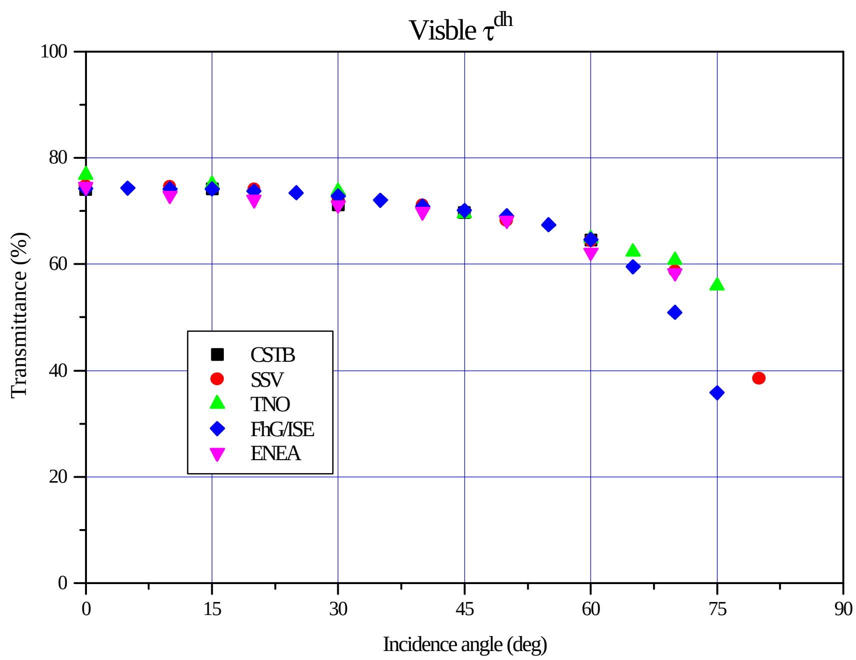


Figure 4: Visible directional/Hemispherical transmittance on diffusing sample

The directional measurements (figure 4,5 and table 10) confirm the difficulties related to the measurement of the optical properties of the diffusing samples.
The results are in relatively good agreement when the same procedure is used.

Directional/Hemispherical Transmittance										
	Integrated visible factor					Integrated solar factor				
angle deg	FhG/ISE	CSTB	ENEA	SSV	TNO	FhG/ISE	CSTB1	ENEA	TNO	TIL
0	74.2	74	74.5	74.7	76.8	83.9	79.5	81.8	84.3	83
5	74.3	--	--	--	--	84	--	--	--	--
10	74.1	--	72.9	74.6	--	84.2	--	80.7	--	--
15	74.1	74.2	--	--	75	83.2	75.8	--	82.6	--
20	73.7	--	72.1	74.1	--	83.1	--	79.4	--	--
25	73.4	--	--	--	--	83.1	--	--	--	--
30	72.8	71.2	71.1	72.7	73.7	82	73.5	78.2	81.1	80
35	72	--	--	--	--	82.1	--	--	--	--
40	70.9	--	69.8	71.1	--	81	--	76.7	--	--
45	70.1	69.7	--	--	69.5	--	71.3	--	76.7	76
50	69.1	--	68.2	68.2	--	78.3	--	73.9	--	--
55	67.4	--	--	--	--	76.1	--	--	--	--
60	64.6	64.52	62.2	64.4	64.8	72.2	64.5	67.6	70.1	68
65	59.5	--	--	--	62.3	65.4	--	--	66.8	--
70	50.9	--	58.3	58.7	60.7	55.7	--	60.6	62.5	59
75	35.8	--	--	--	55.9	35.6	--	--	57.5	--
80	--	--	--	38.5	--	--	--	--		--

table 10: Directional/Hemispherical transmittance on diffusing sample

CSTB spectral measurement
SSV broadband measurement, reference Illuminant A
TNO broadband measurement, reference air mass 2.

4-2.b. Conclusion

The comparison of the experimental results on the measurements of the optical properties from the diffusing sample is not easy. The results are drastically dependent on the instrument and the experimental procedure. The OBU laboratory confirms this fact in their report where the optical properties of the sample measured with two instruments are compared.
The use of an iris to fix the ratio between the beam size to the sphere aperture and the dimension of the sphere may be necessary to improve the measurement of the diffuse transmittance component.
It is necessary to apply corrective calculations to these measurements to improve the result.
Further work will concentrate on improving and standardising the experimental and error correction procedures

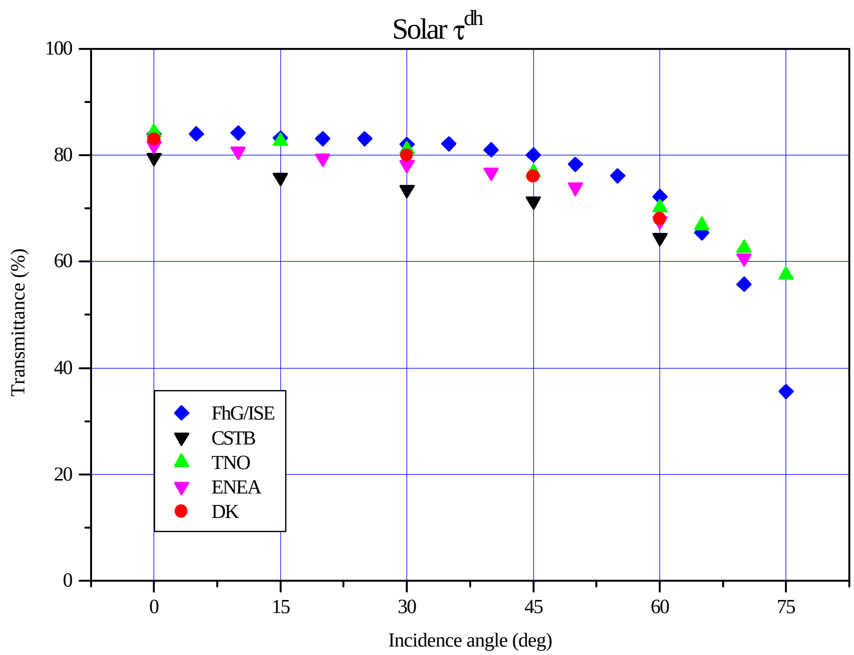


Figure 5: Solar directional/Hemispherical transmittance on diffusing sample

4-3. GEOMETRIC MEDIA - TRANSPARENT INSULATION MATERIEL

This part presents the optical characterization of the directional/ hemispherical transmittance of structured glazing units.
The samples were distributed by the FrG/ISE to all laboratories. Laboratories have performed measurements.
This report presents the results and shows the difficulties encountered in the measurement of the large structured glazing units
The references of the glazing unit samples are OKALUX, AREL

O1 is a 80 mm double glazing with Okalux capillaries inside
O2 is a 40 mm double glazing with Okalux. capillaries inside
A1 is a 100 mm double glazing with Arel capillaries inside
A2 is a 50 mm double glazing with Arel capillaries inside

4-3.a. Results

Results for the OKALUX sample

The table 11 and 12 show the integrated optical factors for the different OKALUX units.
The results show a very good agreement between the laboratories. The comparison of the transmittance curves (fig 6 and 7) confirm this good agreement. We can explain the difference between the solar factor of the CSTB and the other with the difference of the sample: All laboratories have performed the measurements with 6 mm glass for the double glazing with Okalux capillaries inside, CSTB had a 4 mm glass. The solar factor of a 4 mm float glass is 85% and only 81 % for the 6 mm float glass. We don’t see any difference for the visible factor because this factor is nearly the same for 4 and 6 mm float glass(90 and 89 %)

Directional/Hemispherical Transmittance double glazing with 80 mm Okalux capillaries inside									
	Solar factor					Visible factor			
incidence	CSTB	FIN	FrG-ISE	TNO	UWCC	CSTB	FIN	FrG-ISE	TNO
0	69	--	64.4	--	67.0	78	79.1	76.7	--
5	--	--	63.0	--	65.8	--	--	76.0	--
10	69	62.6	61.0	63	64.7	78	77.6	75.3	80
15	68	--	61.6	--	63.4	77.5	76.5	74.7	--
20	--	--	60.3	--	62.1	--	--	74.0	--
25	--	--	59.6	--	60.6		--	72.6	--
30	66	--	57.5	59	59.0	74	71.7	71.9	77
35	--	--	55.5	--	57.1	--	--	70.5	--
40		--	52.7	--	55.0		--	68.5	--
45	59	--	51.4	51	52.5	67.5	--63.8	66.4	69
50	--	--	48.6	--	49.5	--	--	62.3	--
55		--	45.2	--	45.8	--	--	57.5	--
60	43	--	39.7	--	41.0	49	49.7	52.1	55
65	--	--	33.6	--	34.6	--	--	44.5	--
70	--	--	25.3	--	25.4	--	--	34.9	36
75	--	--	16.4	--	10.8	--	23.8	24.7	

Table 11: integrated factor of DGU O1

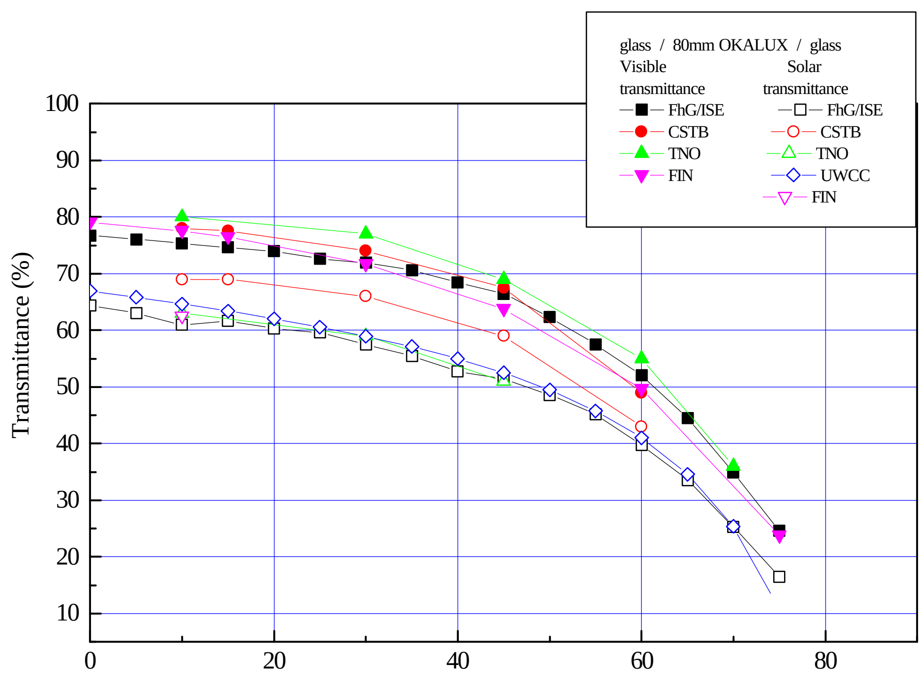


figure 6: Transmittance of DGU with O1

Directional/Hemispherical Transmittance: double glazing with 40 mm Okalux capillaries inside		
	Solar factor	Visible factor

incidence	FIN	FrG-ISE	TNO	UWCC	TIL	FIN	FrG-ISE	TNO
0	--	66.2	62.9	67.5	61	78.1	77.7	79.2
5	--	64.2	--	66.4	--		77.7	--
10	62.6	66.2	60.6	65.2	--	77.6	77.0	77.3
15	--	64.2	--	64.0	--	76.7	76.5	--
20	--	64.2	59.9	62.7	--	--	75.7	76.3
25	--	62.2	--	61.2	--	--	74.3	--
30	--	62.2	59	59.6	--	74.6	73.6	76
35	--	59.5	--	57.8	--	--	73.0	--
40	--	58.8	56.5	55.7	--	--	72.3	73.6
45	--	58.1	--	53.2	53	70.7	71.6	--
50	--	55.4	49.4	50.2	--	--	68.2	64.6
55	--	52.0	--	46.5	--	--	63.5	--
60	45.1	47.3	38.3	41.8	42	59.9	58.1	51.7
65	--	39.2	--	35.4	--	--	50.7	--
70	--	30.4	22.9	26.2	--	--	41.2	32.6
75	--	24.3	--	11.6	--	36.9	30.4	--

Table 12: integrated factor of DGU with O2

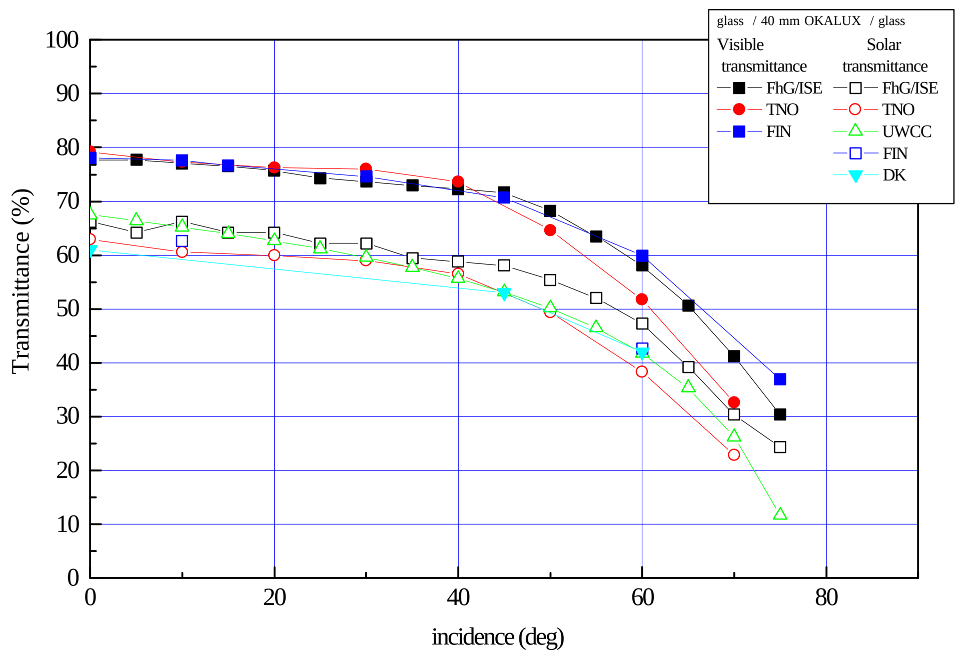


Figure 7: Transmittance of DGU with O2

<u>Results for the AREL sample</u>

It is very difficult to compare the experimental results on the AREL units because the samples were different. The table 13 shows each sample measured by each laboratories

Laboratories	Sample
CSTB	4 mm float glass / 100 AREL / 4 mm float glass
FrG - ISE	3 mm low iron glass / 50 AREL / 3 mm low iron glass
FrG - ISE	3 mm low iron glass / 100 AREL / 3 mm low iron glass
SSV	50 mm AREL
SSV	4 mm float glass / 50 AREL / 4 mm float glass
TNO	6 mm float glass / 100 AREL / 6 mm float glass

TNO	6 mm float glass / 100 AREL / 6 mm float glass
FIN	50 mm AREL
FIN	100 mm AREL
FIN	3 mm float glass / 50 AREL / 3 mm float glass
FIN	3 mm float glass / 100 AREL / 3 mm float glass
UWCC	3 mm float glass / 50 AREL / 3 mm float glass
UWCC	3 mm float glass / 100 AREL / 4 mm float glass

Table 13: AREL sample measured by laboratories

The figure 8 and 9 summarises all the experimental results. We note that the differences between the curves are in good agreement with the different configurations of the sample

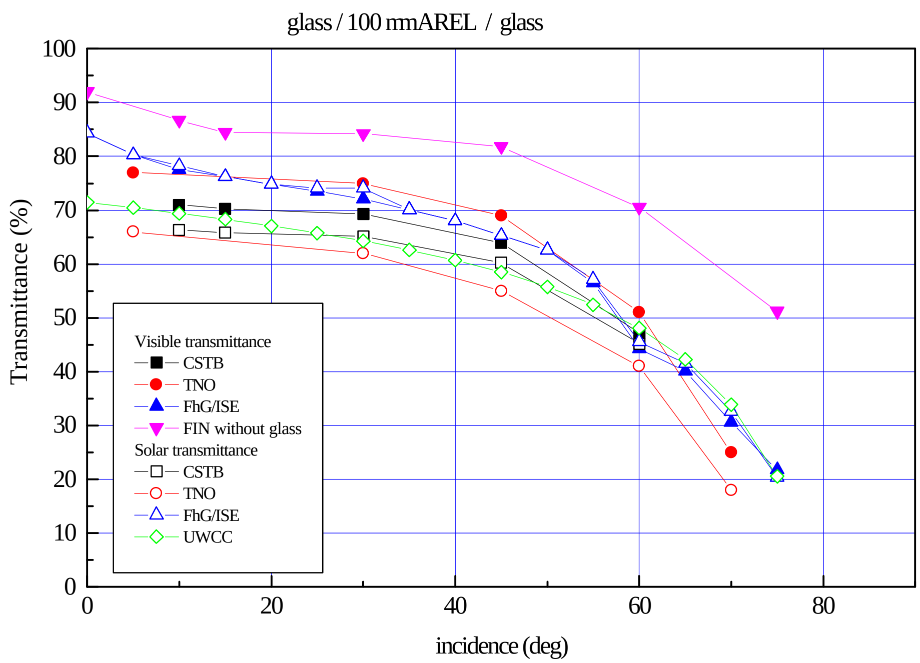


Figure 8:Directional transmittance of DGU A1

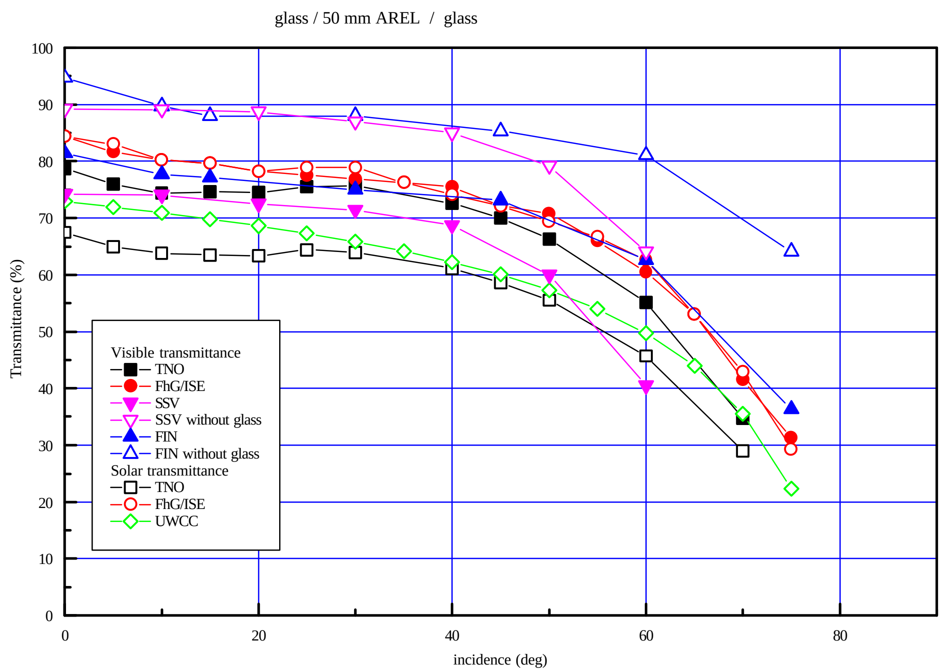


Figure 9: Directional transmittance of DGU A2

4-4. AEROGEL WINDOW

The thermal and optical properties of monolithic silica aerogel make the material very interesting as an insulating element in a double glazed unit.

An aerogel DGU can be constructed as a sandwich consisting of a 20 mm thick aerogel plate between two glass panes. The unit is sealed (the edge seal) and the aerogel is evacuated below 50 mbar.

In order to measure these parameters, four units have been distributed to four different labs within Task 18 (FIN,FRG,FRA,DK):

Optical properties of the aerogel window were investigated. The directional-hemispherical transmittance (τ^{dh}),the directional-directional transmittance (τ^{dd}) and the directional-directional reflectance (ρ^{dd}) were measured for the spectral range 400 - 1800 nm. From these data only the integrated values for the solar transmittance and the visible transmittance were calculated, using the CEN prEN 410 with the document air mass 1 solar spectrum for the solar integration.

4-4.a. Results

All following results come from CSTB (FRA) and VTT (FIN). Figures 10, show the directional-directional transmittance, the directional-hemispherical transmittance and the directional-directional reflectance. The table 14 summarizes the results of the measurement with integrated factors

Angle of incidence	τ_v^{dh}		τ_e^{dh}		τ_v^{dd}	τ_e^{dd}	ρ_v^{dd}	ρ_e^{dd}
	FRA	FIN	FRA	FIN	FRA	FRA	FRA	FRA
0	71.7	73.7	74.1	74.9	49.7	56.3	/	/
15	71.2		73.7		48.2	55.1	8.8	8.9
30	68.2		71.3		45.4	53.3	9.4	9.6
45	63.6		67.9		39.8	49.5	13.2	13.1
60	42.9		49.7		24.3	35.6	/	/

Table 14 : Optical results of Aerogel DGU

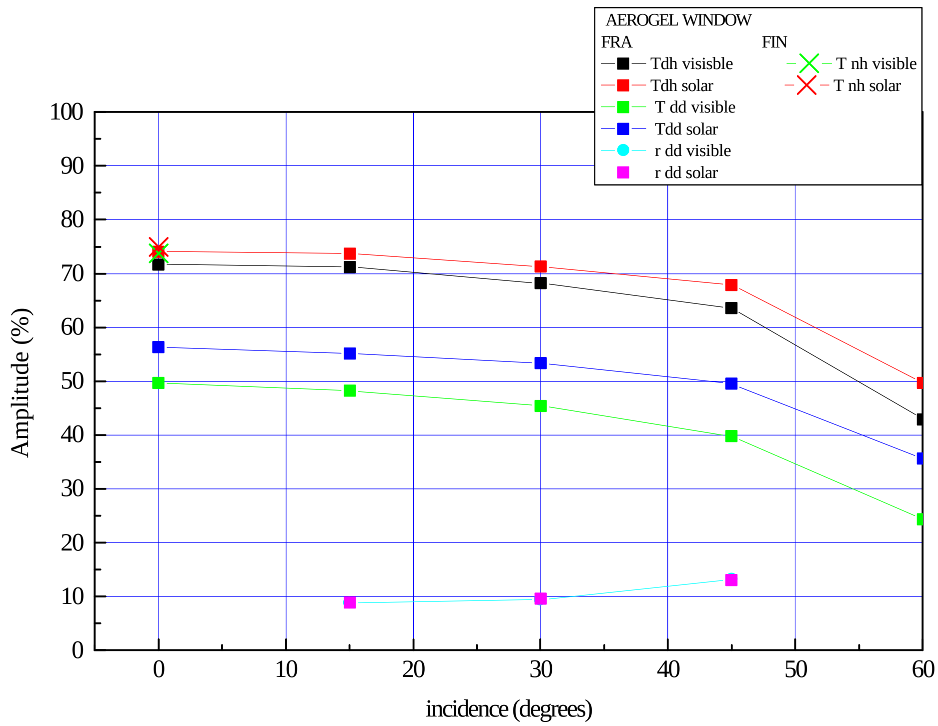


Figure 10 :directional optical factors of Aerogel DGU

4-5. GEOMETRIC MEDIA - DAYLIGHTING SYSTEMS

This part presents the optical characterization of the directional/ hemispherical transmittance of daylighting systems.
The ISOFLEX sample was delivered as a DGU with a U-shaped galvanised steel profile as spacer The acryl sheets were attached to the U-profile by means of double adhesive tape. The thickness of the ISOFLEX material is 50 mm.
The Hunter Douglas sample was a sealed double glazing unit. The first pane was clear float glass (4 mm thickness) the second one K glass with coated face facing the air gap. Between the glass a series of rotable slats were located.

4-5.a. results

results for ISOFLEX sample

Figure 11 shows the integrated optical factors versus the incidence angle for the ISOFLEX unit. The curves show a very good agreement between the laboratories.

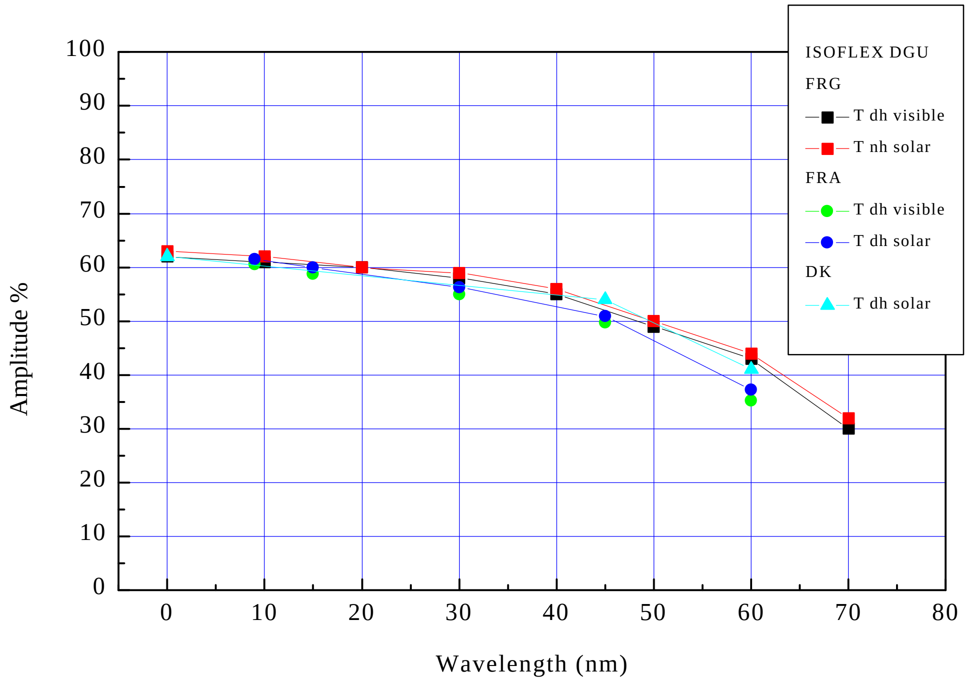


Figure 11 : optical factors versus incidence angle for the ISOFLEX DGU

results for Hunter Douglas sample

Figure 12 shows the convention on the incident angle and slats position. The measurement conditions of each laboratories (CSTB, ENEA, FhG/ISE) were different so the curves Figure 13 and 14 show a summary of all results

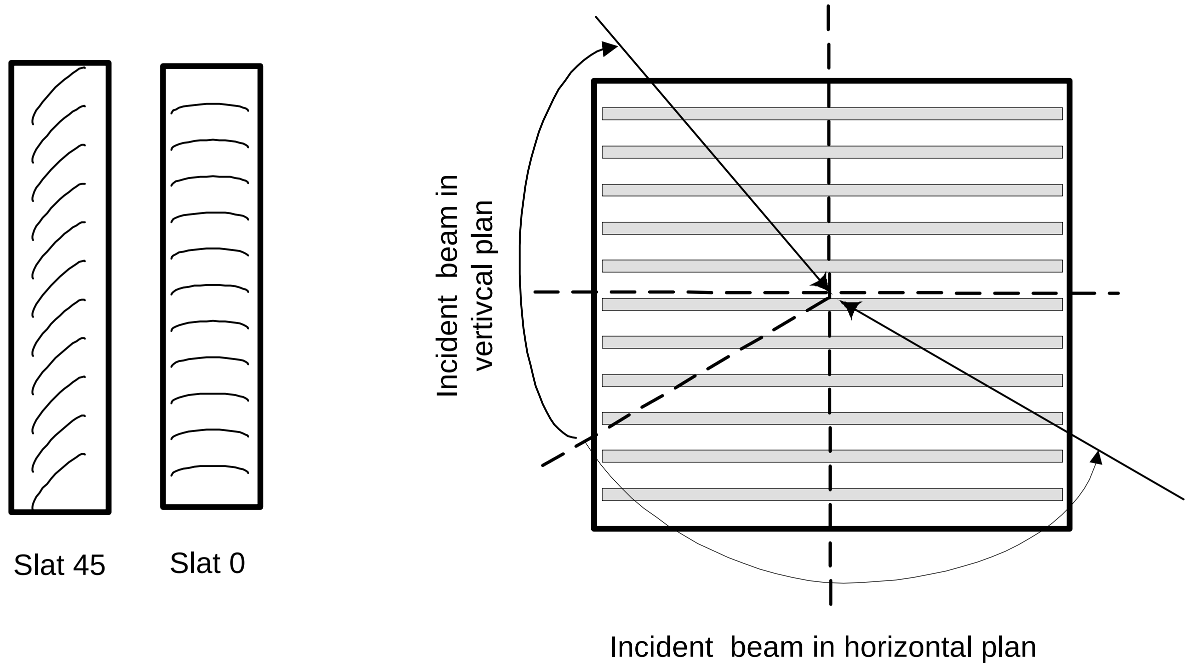


Figure 12: Slat position and incident beam angle convention

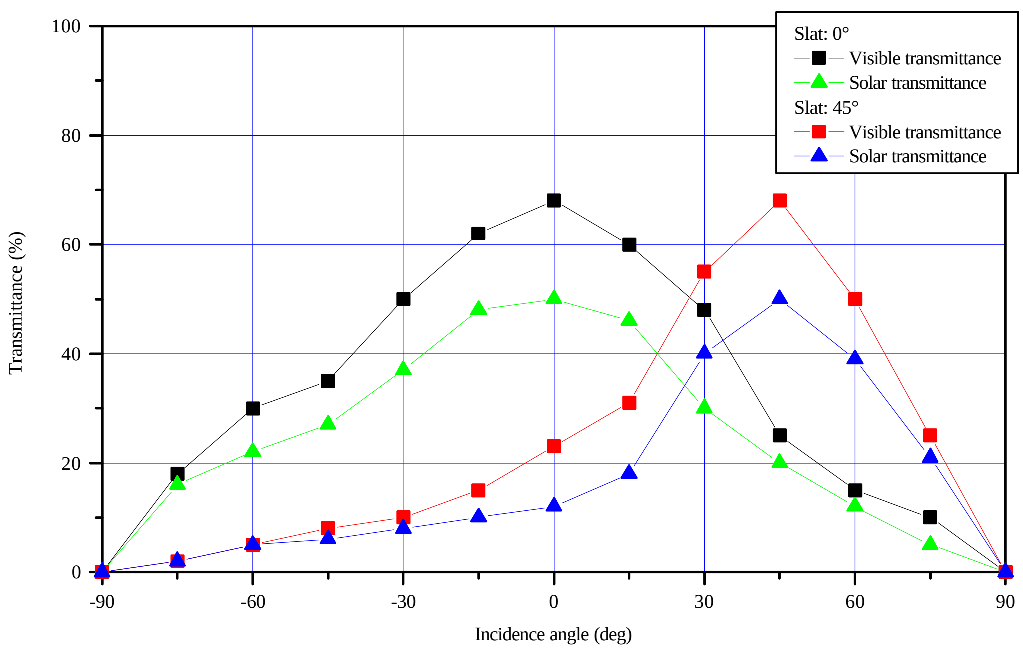


Figure 13: directional hemispherical transmittance versus incident angle in the vertical plan of Hunter Douglas sample

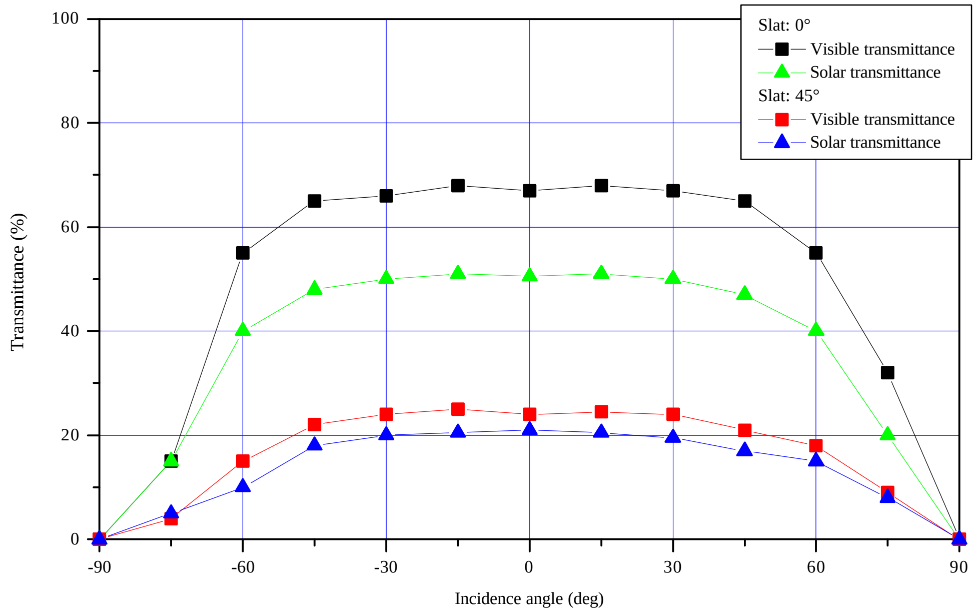


Figure 14: directional hemispherical transmittance versus incident angle in the horizontal plan of Hunter Douglas sample

5 MEASUREMENT RECOMMENDATIONS

When analysing the results and trying to explain the discrepancies or the good fit of the data, one can make a clear statement on how we can be more precise and improve our measurements procedures.

The summary of these recommendations are contained in the table 15, as a result of the common work of the B13 participant. Table 16 show the measurement problems (code from the table 16) according the material families.

Code	Sample property	Problem	Precaution measure
1	Scattering	- sphere response/detector f.o.v.	correction dep. on sphere and degree of diffusion
2	Spectral selectivity	- broad band detection / wrong simulator spectrum or no even sensitivity	spectral correction with device function, simulator spectrum and relative spectral transmittance
3	Heterogeneity	- proper average with respect to illumination and detection	check relation between illumination area, detection area and periodicity dimension; if outside, average of several measurements
4	Thickness	- radiation escapes aperture port - intensity change along divergent beam	check relation between illumination area, port area and sample thickness correct reference level (dependent on position and degree of scattering plane)
5	Anisotropy	- uneven internal intensitiy distribution / detector f.o.v.	possible: 2π-detector or approximate: rotation of sample and interpret changes
6	Angular Selectivity	- divergent beams avergae out steep changes in properties ($d^2\tau/d\theta^2$ _0)	numerical treatment (dependent on situation and material)
7	Internal capture of light	- radiation escapes	remedy by geometry or integration of glazing in the sphere
8	reflectance of sample	- change of sphere sensitivity	measure effective reflectivity, correct sensitivity or extrapolate to zero aperture with several measurements
9	temperature dependent prop's	- change of temp. due to absoprtion with illumination; not defined states	control temperature of sample
10	phototropic response	- change of state with illumination, not defined state	control illumination level

	Code of problem	glazing unit Families	EXAMPLES
Single Glazing Unit	*8*	**Clear or coated Specular materials**	clear or tinted glass, polymer., coated glass, laminated glass
	1,4,**7**,*8*	**Diffusing homogenous materials**	diffusing tinted glass, diffusing polymer, aerogel, diffusing coated glass or laminated glass
	1,**3**,5,*8*	**Low thickness Heterogeneous materials**	woven solar protection, printed glass
	1,**3**,**4**,**5**,**6**,*8*, *9*	**Geometric media**	Multi ribbed wall, venetian blinds,
Complex Glazing Unit	4,*8*	**Clear or coated Specular CGU**	clear or specular coated complex glazing with or without plastic film inside
	1,**3**,4,5, **7**,*8*	**CGU with Diffusing or low thickness Heterogeneous materials**	CGU with diffusing or printed pattern, CGU with static laminated shading blinds
	1,**3**,**4**,**5**,**6**,7, *8*,*9*	**CGU with transparent insulator materials**	CGU with capillary material
	1,**3**,4,**5**,**6**, *8*	**CGU with fixed or moving blind**	CGU with static laminated shading blinds, CGU with venetian blinds
	1, **4**, 5, 7,*8*,9,10	**CGU with variable transparent glass**	CGU with electrochrome, photochrome and thermocrhome composants

 # main problem
normal problem
 # less of a prblem

To solve each problem many discussion are currently in progress. These discussions are essentially about the relative geometry of the large integrating sphere, the dimensions of the sample and the diameter of the incident beam (fig 15). It will be necessary to make some correction like:

- correct the measurement at θ with the no sample response of the integrating sphere at the same angle θ
- correct the reflection of back side of the sample or compensate the substitution error

or check some parameters like

- the sensitivity of the sphere system (Including detector f.o.v.) to the scattering properties of the sample and the reference
- The gross dimension of the sample must exceed the aperture diameter at least with 4 times the sample thickness
- the beam parallelism ± 8 degrees
- the port-beam# = half of the absolute value of the difference (port ϕ- beam ϕ) see fig.15
- check the ratio[thickness of sphere wall]/[aperture] (< 5% or bevelled edge > 60°)
- the ratios[aperture ϕ]/ [heterogeneity mesh of the sample surface] and [beam ϕ]/ [heterogeneity mesh of the sample surface] (>10)

For each material families these procedure are unnecessary important or mandatory in function of the sample properties and the associated problem.

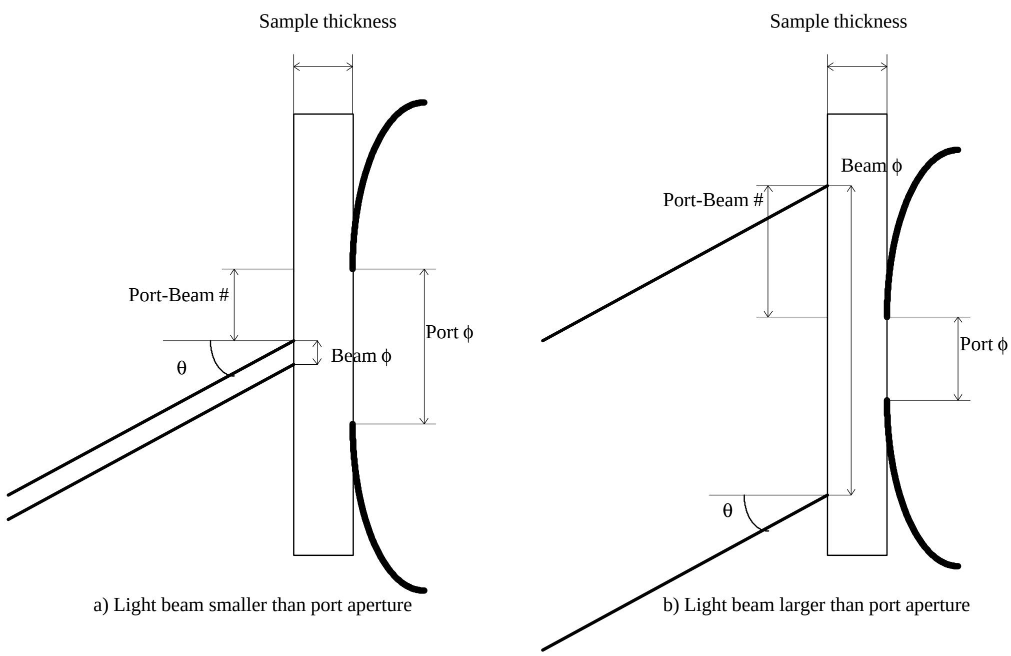


Figure 15: Geometry of different configuration measurement with a large integrating sphere

6 CONCLUSIONS AND PERSPECTIVES

From the content of the previous chapters, we can now say that the aim of the project, expressed in the introduction, has been fulfilled to a greater extend: our knowledge of directional optical properties of several glazing materials has been improved, we have harmonized our terminology, we know more details about the common measurement capabilities, and we have elaborated on some measurement procedure recommendations.

We are convinced of the interest for directional characterisation but maybe some demonstration of that interest is now expected to show the benefit of it for more accurate comfort and energy saving calculations. This work is possible using the large number of data produced for several product families : this could be done in a future working group.

All the following task 18 participant laboratories are now able to perform relevant directional optical measurement on a new product, and will probably be in agreement if measuring the same sample : this is also an important benefit of the project.

The next step is probably to convince the product manufacturers and the regulations people of the need for directional optical measurement.

Fortunately, the European Community gives us the opportunity for progressing towards that aim as two projects designed within task 18 ("ALTSET" and "ADOPT") have granted funding in the Measurement and Testing program (beginning January 97)

So the work began by the B13 project, described in this report, will go on through these new projects.

Participants with man months commitment

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